DESIGN OF SPRAY NOZZLES AS APPLIED TO DE LA VERGNE OIL ENGINE

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THE STUDY AND DESIGN OF SPRAY NOZZLES AS APPLIED TO THE DE LA VERGNE OIL ENGINE

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Oil Engine Spray Nozzles.

Introduction.

In the past few years exhaustive experiments have been made on fuel injection into the cylinder of oil engines. The excessive cost of power with steam and gas engines has aroused interest in the fuel oil engine, and placed it in the commercial field.

As the principle feature and the sale basis for the success of the engine lies in the fuel injection, the spray nozzle has been given more attention than any other particular phase. Since the nozzle is a long way from being in the state of perfection, all experimental tests on the performance of oil engines should give the nozzle special attention. Hence, we have chosen the study of the spray nozzle to be the chief object of the experimental tests herein treated.

Realizing the superior quality of some of the existing treatises upon this subject, and due to the limited time for our investi-

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gation, we shall not endeavor to treat all of the phases entering into the construction of a practical and commercially successful nozzle, but will devote our time in determining, from a selection of various types of nozzles, the most adequate for practical application to a single cylinder De LaVergne Oil Engine. We shall also briefly discuss the design, construction, and operation of this particular engine, as the type of engine is a controlling factor in the kind of nozzle best suited to do the work.

Naturally the grade of fuel used greatly influences the results obtained, hence tests should be made with several different grades of fuel.

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Historical:-

Due to the small difficulties in vaporizing the lighter oils, such as benzine, naphtha, and gasoline, early internal combustion engines used these fuels. However, it soon became apparent that an engine using the heavier oil fuels, such as crude oils, kerosene and shale oils with success, would find a ready market due to the lower cost of the latter fuels. The heavier oils are subject to a recondensation when vaporized so this led up to the use of a heated vaporizer incorporated in the cylinder. The oil was injected through a spray nozzle onto the heated surface. It is an established fact that the more thorough the atomization of the oil, the more complete will be the combustion of the charge. A thorough atomization reduces the tendancy to form carbon on the vaporizer and cylinder. The above facts led many to undertake the design of dif-

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ferent nozzles and to note their effect on the operation and fuel consumption of the oil engine used for our proposed tests.

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Object.

In view of the increasing use of oil fuels due to their lower costs, and also to the fact that the demand for gasoline is fast overtaking the production, the engine using the heavier oils is rapidly coming into prominence. The operation of the oil engine in regard to economy, ease of operation, etc., depends a great deal on the thorough atomization of the fuel. Therefore, the design of the spray nozzle is an important feature of the engine.

This condition calls for a study of the effects of the various designs of spray nozzles for the oil engine. The investigations are made on a single cylinder De LaVergne Oil Engine operating under the two cycle principle, with hot tube type ignition.

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Apparatus.

Cycle of Operation:- This test was conducted upon a 7" x 7 1/2" single cylinder, 7 H.P. De LaVergne vertical oil engine operating under the two cycle principle. Air is taken through a spring air valve into the crank case on the up stroke of the piston and at the same time the products of combustion in the head end of the cylinder are discharged through the exhaust valve located a trifle above the center of the cylinder. On the down stroke the air in the crank case is forced up through an air passage in the cylinder walls into the head end of the cylinder. Here it is mixed with a spray of oil injected through a nozzle by a pump located along side of the main bearing on the flywheel side. The mixture is now compressed on the up stroke of the engine, and exploded by a vaporizer in the cylinder head, which is heated by means of a torch playing on it.

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Torch:- The torch may be fired with either kerosene or gasoline. For fire prevention purposes it is advisable to use the former, but if a quick heat is required, gasoline will give the best results.

Lubrication:- It is essential that all bearings and moving parts be thoroughly oiled as difficulty will be encountered in starting if there is any binding of the engine. To obtain this desired lubrication, oil cups are placed not only on all bearings, but also on two sides of the cylinder, from which, oil is drawn on each down stroke of the piston, thus reducing the friction of the piston travel to a minimum. There is an oil ring cut in the crank arm concentrically with the axis of the shaft. Oil is fed into this groove by the projection of the shank of an oil cup. From the groove, oil flows through a hole drilled diagonally from the edge of the groove to the periphery of the crank pin. This is a very neat

and efficient manner of lubricating the crank pin. Of course, the crank pin receives considerable oiling by splashing of the oil in the crank case.

Cooling:- The main bearings, cylinder walls, and head are cooled by water entering at the main bearings and leaving from the cylinder head. The water cooled bearings, although not essentially necessary, is a very commendable feature in this engine. Pet-cocks are placed in the lower part of the engine for draining the crank case and the water jacket.

Brake:- The load on the engine may be governed by a water brake placed at one of the extremities of the crank shaft. This brake consists of two copper circular disks encased by two cast iron plates. Water is circulated between the cast iron and copper plates, thus creating a pressure between the two copper disks. This increases the frictional resistance between them, which tends to stop the

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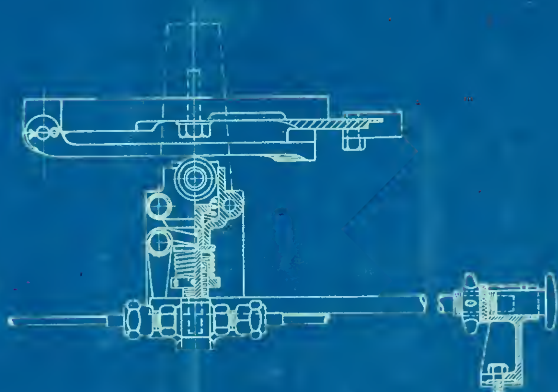
rotation.

Oil Pump:- One of the most interesting parts of the oil engine is the oil pump. The success of the engine lies upon its ability to pump the oil in the proper time, with enough pressure to force the fuel through the atomizing device of the nozzle, in an extremely fine spray. Furthermore, it must have a quick short stroke as the fuel for each revolution must be injected into the cylinder within a small fraction of a second.

The pump consists of a steel plunger ground in the brass body of the pump. Packing is provided to insure tightness, although not tight enough to hamper the return stroke of the plunger which is actuated by a steel spring coil. On the return stroke of the plunger, oil is drawn up through a check valve into the cylinder of the pump. The force stroke is provided for by the governor cam pressing upon a roller mounted on a steel drum ground in the



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brass casing of the pump body. The pump may also be operated by hand, through a lever connected to an extension rod on the side of the cylinder. This mechanism is best understood by the self explanatory illustration on page 10

Hot Bulb:- The mission of the hot bulb is that of furnishing the high temperature required in vaporizing the fuel. This temperature must not reach too high a point as the engine will pound due to excessive initial pressure. The bulb should occasionally be cleaned as the decomposition of deposits of fuel formed on it will not only make it harder to heat, but may cause cracking. The bulb is made of cast iron and is cast in the cylinder head. It is enclosed in an iron hood in order that the radiation losses may be reduced to a minimum. It is only necessary to heat the bulb in starting, as, after the engine is running, the heat of combustion is great enough to maintain the heat in it.

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Nozzle:- The type of nozzle used if this engine is illustrated on page 13. The oil enters the nozzle in a fine stream under heavy pressure. It passes through a spring ball valve, thence into the spray nozzle, where it is broken up by passing through the spiral grooves in the spray pin, and out of the small hole in the tip of the nozzle. The design and construction of the nozzle will be taken up in further detail in the discussion of the test.

Fuels:- Any oil which contains heat units will vaporize when it comes in contact with the hot surface of the vaporizer, and will consequently develop pressure. This being the case any fuel could be used. But with light oils, such as kerosene, the flame propagation is more rapid than with fuel oil or a heavier grade of distillate. This fact interfers with operation on either grade of fuel as the flame propagation is dependent upon the temperature of the hot bulb and timing of the injection of

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the fuel. The timing of the injection is by far the most important of these two points, for if it is set right for fuel oil it will be too early for kerosene, and vice versa. As kerosene is more volatile, less difficulty will be encountered in starting. The properties of oil and its adaptability to oil engines will be further discussed in the following chapter.

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Construction.

Before any attempt to run a test was made, the engine was thoroughly overhauled. A crack in the base made it necessary to scrap the old one and install a new one in its place. Care was taken to see that the base was perfectly level and setting firmly on the wedges before grouting. The crank case was thoroughly cleaned and the main bearing inspected before replacing them. The crank pin and its bearings were very badly pitted and it was necessary to scrape and refit both pieces. The cylinder was found to be in very good condition and all that was necessary was a small amount of cleaning. Although the piston itself was in good condition, the piston rings were so firmly incrusted with carbon that it was necessary to remove all of them, those on the head end having to be chopped out. An entire set of new rings were fitted to the piston and after a great deal of time and trouble a perfect fit was ob-

tained with smoothness in piston travel and minimum slip or leakage insured. The oil pump, cups, water brake, vaporizer, and nozzle were all thoroughly cleaned and oiled before replacing. In replacing the shaft and cylinder great care was taken in cutting gaskets in order that the engine would turn over with ease and still give the proper compression space in the crank case. Each part of the engine was carefully inspected and thoroughly oiled before connecting it up. This precaution was taken in order that any trouble caused by faulty construction might be avoided.

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Discussion.

General:- The foundation of success, lies in a thorough knowledge of the basic fundamental principles involved in the subject in which success is attained. This being the case, it will be necessary to study the physical and chemical properties of the fuels, with which the nozzle has to deal, before an intelligent analysis of the latter can be made.

Fuels:- Liquid fuels are of great moment, in view of the recent development of the petrol engine and the increasing use of heavy and waste oils. The heavier oils are more generally used in engines of the Diesel type. Although these oils may be used to good advantage in the De LaVergne engine, it has been found that the lighter oils give better results. The use of light oil is better than the heavy oils because of its greater volatility, and accordingly the lighter oils are recommended for use in this engine.

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Crude petroleum is by various processes of distillation, separated into the following seven main products for commercial use:-

1. Petroleum ethers.
2. Naphthas, benzines or petrols.
3. Illuminating oils, burning oils or kerosenes.
4. Intermediate, or gas oils.
5. Lubricating oils.
6. Residuum.
7. Paraffin wax.

The oils available for use as fuel in this engine are those of the third and fourth class, i.e. burning and intermediate oils. Burning oils are known in America as kerosenes and have a specific gravity ranging from about 0.78 to 0.83. The kerosene known as Russian oil, and, having a specific gravity of 0.825 is considered best suited as fuel for oil engines. For power purposes it is important that the oil used shall have no tendency to produce tarry

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deposits.

Kerosenes are mixtures of hydrocarbons and their lack of homogeneity is illustrated by the following results obtained by Professor Robinson in some fractional distillation experiments:

Description of Oil	American kerosene White Rose	American Royal Daylight	Russian kerosene
Specific gravity	0.784	0.797	0.825
Flashing point	105° F	81° F	88° F
Vapor temperature at which distillation commences	293° F	257° F	239° F
Distillates	Per cent	Per cent	Per cent
Spirit below 300° F	7	23	20
Kerosene 300° F to 520° F	85	54	68
Distillate above 520° F	5	10	9
Residue at 680° F	3	13	3

D. Clerk & G. A. Burles, Vol. 2, page 456.

Professor Robinson also found that all kerosenes may be vaporized by blowing dry air or dry steam through the oil when heated to

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about 500°F. When the oil is sprayed through a nozzle a very large surface is exposed and agitated which assists in evaporation.

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Data.

Time	R.P.M.	Temp. Cooling Water Inlet	Temp. Cooling Water Outlet	M.E.P.	Wt. Fuel		Wt. Cooling Water
11:45	410	49	134	28.7	Tare	23.22	520
11:48	412	49	138	30.85	Gross	25	615
11:51	415	49	139	31.9	Net	1.78	95
11:54	415	49	140	32.9			
11:57	418	49	141	33.9			
12:00	420	49	147	36			
Average	415	49	139.8	32.34			

Barometer: 29.49 Scale of spring: 160#

Brake:		Fuel:	
Gross Wt:	47#	Kind:	Kerosene
Brake Wt:	6.5#	Temp:	67°
Net Wt:	40.5#	Buame	43.5
Brake arm:	2 ft.	Specific gravity:	.8075

Clearance volume cu.ft.	.03460
Diameter cylinder inch	7
Length stroke inch	7
Displacement cu.ft.	.1553
Per cent clearance vol.	22.28

Cycle:

Fuel injection degrees: 46.6° early.

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Calculations.

Clearance:- The clearance volume was determined by removing the cylinder head and placing the piston at the upper end of its stroke. The water was poured into the cylinder above the piston until its level was the same as that of the lower part of the cylinder head when in place. The cylinder head was then filled and these two weights of water added.

Weight of water in cylinder = .24#

Weight of water in head = 1.92#

Total weight of water = 2.16#

At 50°F. the specific volume of water = .01602 cu.ft., per lb. From Mark & Davis

$\therefore$ 2.16 x .01602 = .03460 cu.ft.

Length of stroke = 7 inches
Diameter of cylinder = 7 inches

$$\text{Displacement} = \frac{7 \times (7)^2 \times .785}{1728} = .1553 \text{ cu.ft.}$$

Total volume = .1553 + .03460 = .1899

Per cent clearance = .03460 x 100 ÷ 1899 = 18.2%

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$$\text{I.H.P.} = \frac{32.34 \times 7 \times (.784 \times 49) \times 415}{33000 \times 12} = 9.13 \text{ H.P.}$$

$$\text{B.H.P.} = \frac{6.28 \times 2 \times 415 \times 40.5}{33000} = 6.4 \text{ H.P.}$$

M. Eff. $= 6.4 \div 9.13 = 70.2\ \%$

Fuel Injection:

Diameter of flywheel = 28"

Arc of injection = 11 5/8" before dead center

Circumference = 3.14 x 28 = 88"

$11.375 \times 360 \div 88 = 46.6^\circ$ early

Calorific value of Fuel:

$H = 18650 + 40(43.5 - 10) = 19990$ B.T.U. per lb.

Fuel per hr., lbs. $= 60 \times 1.78 \div 15 = 7.12$ lbs.

Fuel per hr., gal.

Specific gravity = .805

$.805 \times .00202 = .00163$ lbs. per c.c.

$7.12 \div .00163 = 4360$ c.c. per hr.

1 cu. in. = 16.387 c.c. 1 gal. = 231 cu.in.

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$231 \times 16.387 = 3781$ c.c. per gal.

$\therefore 4360 \div 3781 = 1.154$ gal. per hr.

Jacket water per hr.

$= 95 \times 60 \div 15 = 380$ lbs.

Heat given to jacket water per hr.

$= 380(139.8 - 49) = 34550$ B.T.U. per hr.

Total heat supplied per hr.

$= 19990 \times 7.12 = 142100$ B.T.U. per hr.

Heat equivalent of work done per I.H.P. per hr.

$H = 2546 \times 9.13 = 23210$ B.T.U.

Heat equivalent of work done per B.H.P.

$H = 2546 \times 6.4 = 16930$ B.T.U.

Heat supplied per I.H.P.

$H = 142100 \div 9.13 = 15600$ B.T.U.

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Heat supplied per B.H.P.

$H = 142100 \div 6.4 = 22200$ B.T.U.

Fuel supplied per I.H.P. per hr.

$W = 7.12 \div 9.13 = .78\#$

Fuel supplied per B.H.P. per hr.

$W = 7.12 \div 6.4 = 1.11\#$

Heat efficiency per I.H.P.

= Heat converted to work ÷ Heat supplied

$= 23210 \div 142100 = 16.4\%$

Heat efficiency per B.H.P.

$= 16930 \div 142100 = 11.9\%$

Heat lost in exhaust and radiation.

$H = H_T - (H_{IHP} + H_{C.W}) = 142100 - 23210 - 34550$

$= 84340$ B.T.U.

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Jacket water per I.H.P. per hr.

Jacket water per hr. = 380#

I.H.P. = 9.13

∴ water per I.H.P. = 380 ÷ 9.13 = 41.6#

Per cent Heat absorbed by jacket water.

Total heat supplied = 142100

Heat absorbed by jacket water = 34550

Per cent heat absorbed by jacket water

$$= \frac{34550}{142100} \times 100 = 24.3\%$$

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Heat Balance.

Calculations:-

Area of temperature entropy diagram = 5.5 sq.in.

Heat supplied, total = 142100 B.T.U.

Heat converted into work = 23210 B.T.U.

Per cent heat efficiency

$= 23210 \times 100 \div 142100 = 16.34\%$

Heat lost to exhaust gases = area under B.D.

$= 11.63$ sq.in.

$$= \frac{11.63 \times 23210}{5.50} = 49250 \text{ B.T.U.}$$

$= 49250 \times 100 \div 142100 = 34.6\%$

Heat lost to cooling water = 34550 B.T.U.

$= 34550 \times 100 \div 142100 = 24.3\%$

$= 24.3 \times 5.5 \div 16.34 = 8.16$ sq.in.

Heat unaccounted for by unburned gases and radiation by differences

$= 100 - (16.34 + 34.6 + 24.3) = 24.76\%$

$= 24.76 \times 142100 = 35140$ B.T.U.

$= 24.76 \times 5.5 \div 16.34 = 8.34$ sq.in.

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Table:-	Area	B.T.U.	Per cent
Indicated work	5.5	23210	16.34
Heat lost to exhaust gases	11.63	49250	34.6
Heat lost to cooling water	8.16	34550	24.3
Heat unaccounted for	8.34	35140	24.76
	33.63	142150	100.00

Total = 5.5 ÷ 16.34 = 33.63

Table:-	Area	B.T.U.	Per cent
Heat absorbed during compression	.32	1351	.95
Heat added during explosion	13.15	55600	39.0
Heat absorbed by cooling of expansion	4.73	20000	14.05
Heat added by after burning	8.26	34950	24.55
Heat lost in friction	1.492	6300	4.44

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Heat absorbed during compression

$= $ area under C D $= .32$ sq.in.

$= (23210 \div 5.5)\ .32 = 1351$ B.T.U.

Since from preceding table the total heat

$= 33.63$ sq.in.; $.32$ sq.in.

$= (.32 \div 33.63) \times 100 = .95\%$ of total heat.

Heat added during explosion

$=$ area under C A $= 13.15$

$= (23210 \div 5.5) \times 13.15 = 55600$

$= (13.15 \div 33.63) \times 100 = 39\%$

Heat absorbed by cooling during expansion

$=$ area under A Y" $= 4.73$

$= (23210 \div 5.5) \times 4.73 = 20000$

$= (4.73 \div 33.63) \times 100 = 14.05\%$

Heat added by after burning over cooling expansion

$=$ area under Y"B $= 8.26$

$= (23210 \div 5.5) \times 8.26 = 34950$

$= (8.26 \div 33.63) \times 100 = 24.55\%$

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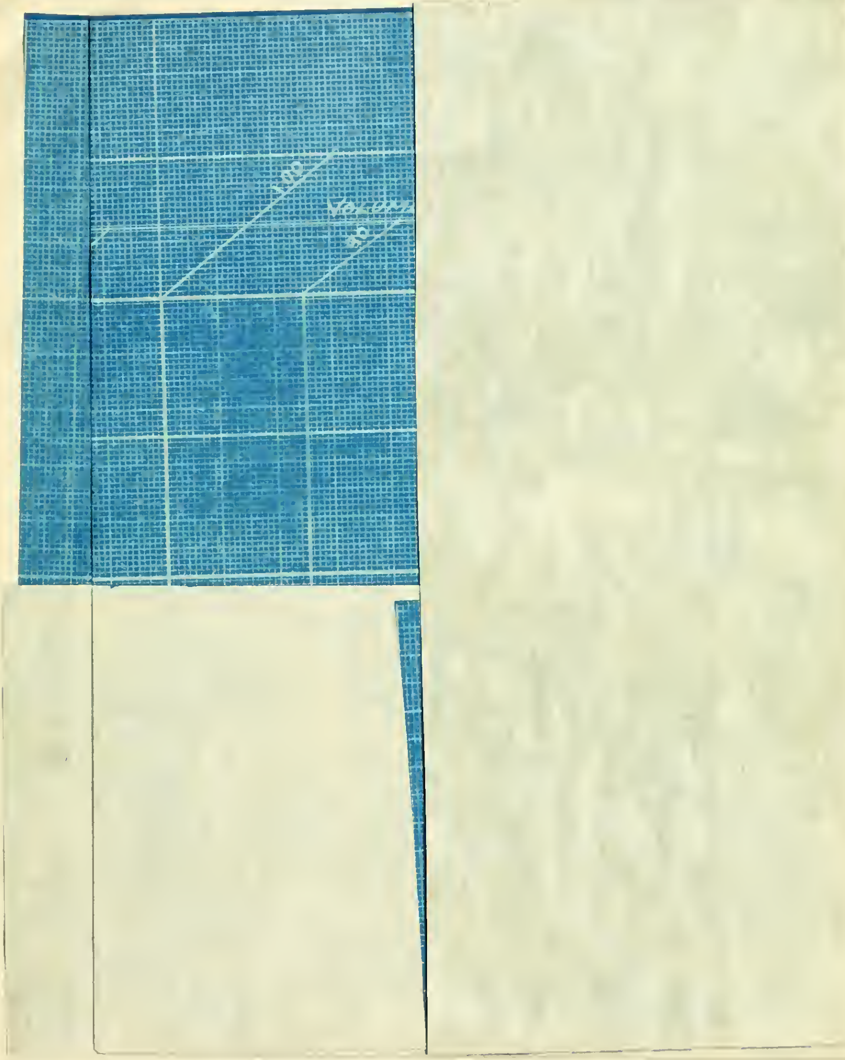
Heat lost in friction

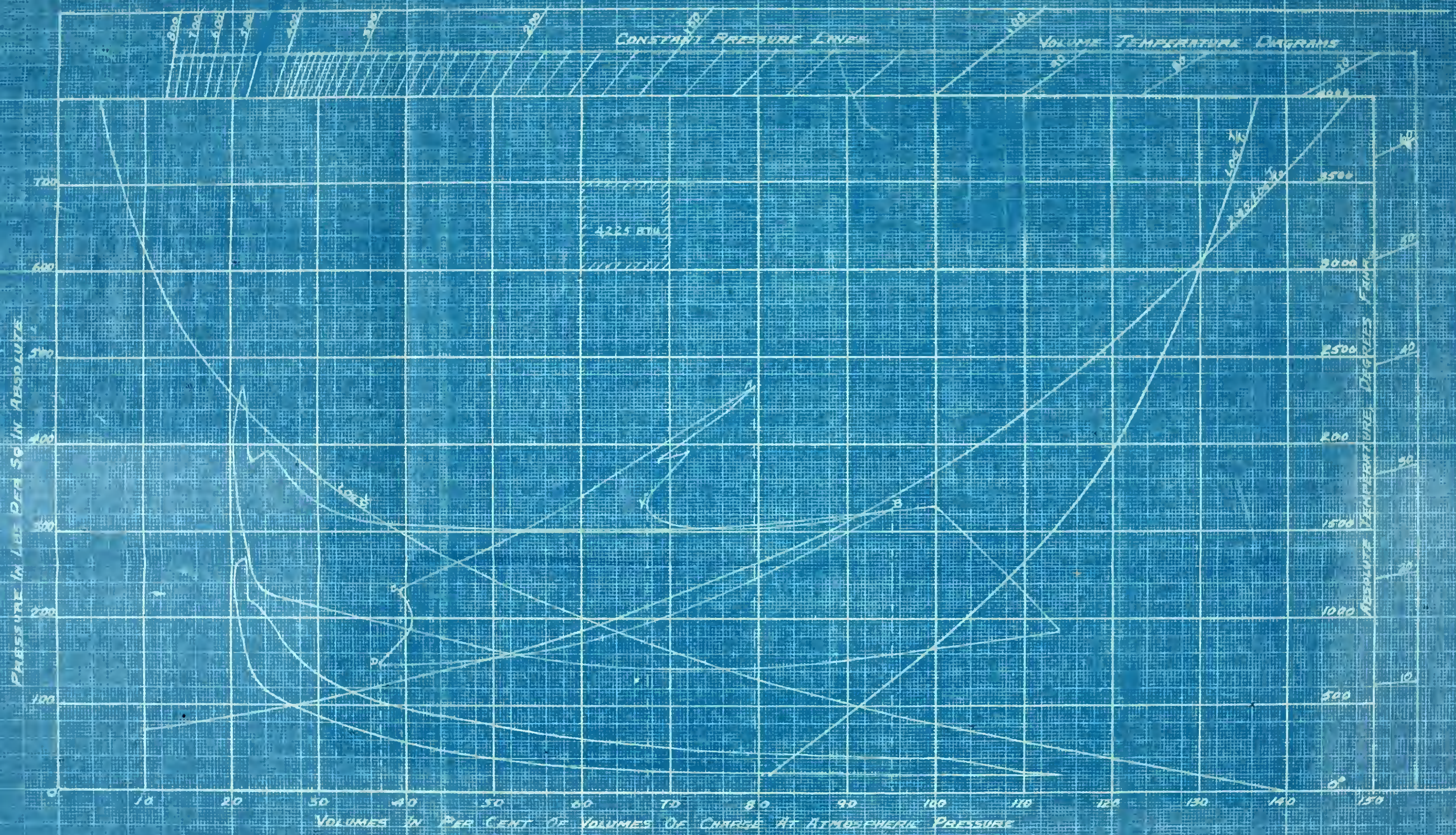
$= $ (heat efficiency per I.H.P.) - (heat efficiency per B.H.P.)

$= 16.34 - 11.9 = 4.44\%$

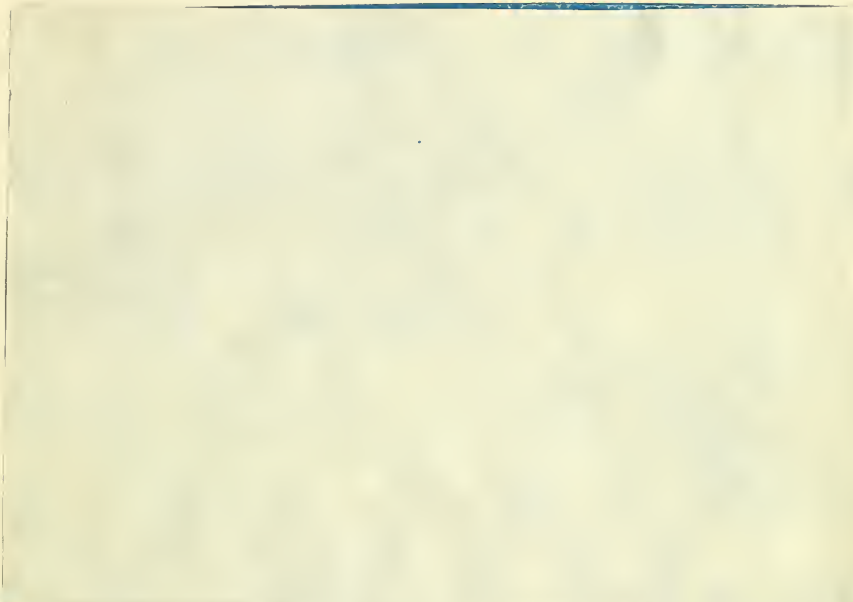
$= (4.44 \times 33.63) \div 100 = 1.492$ sq.in.

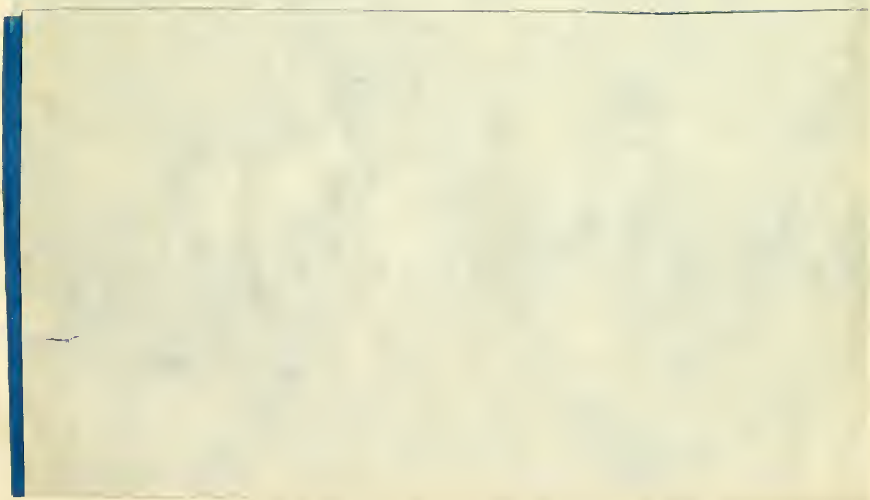
$= (23210 \div 5.5) \times 1.492 = 6300$ B.T.U.

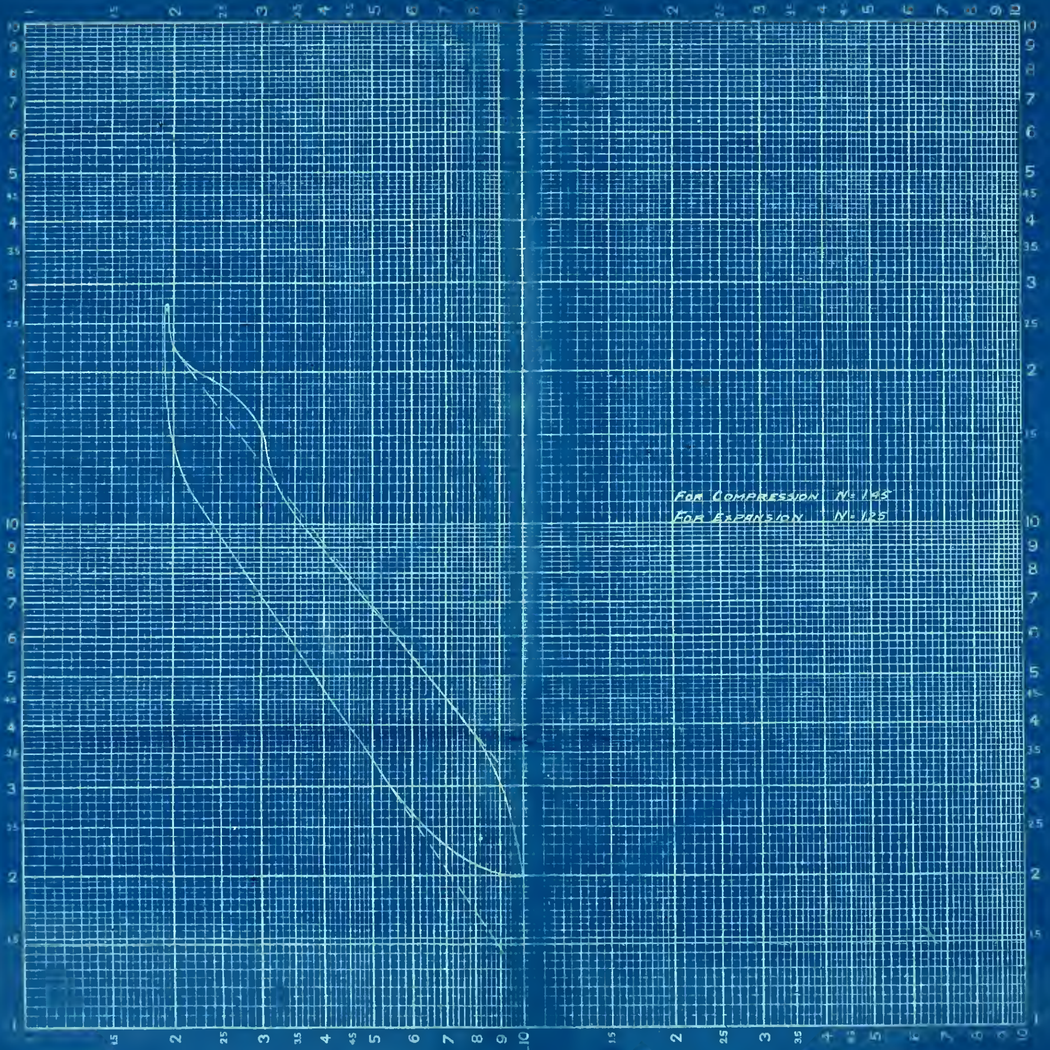


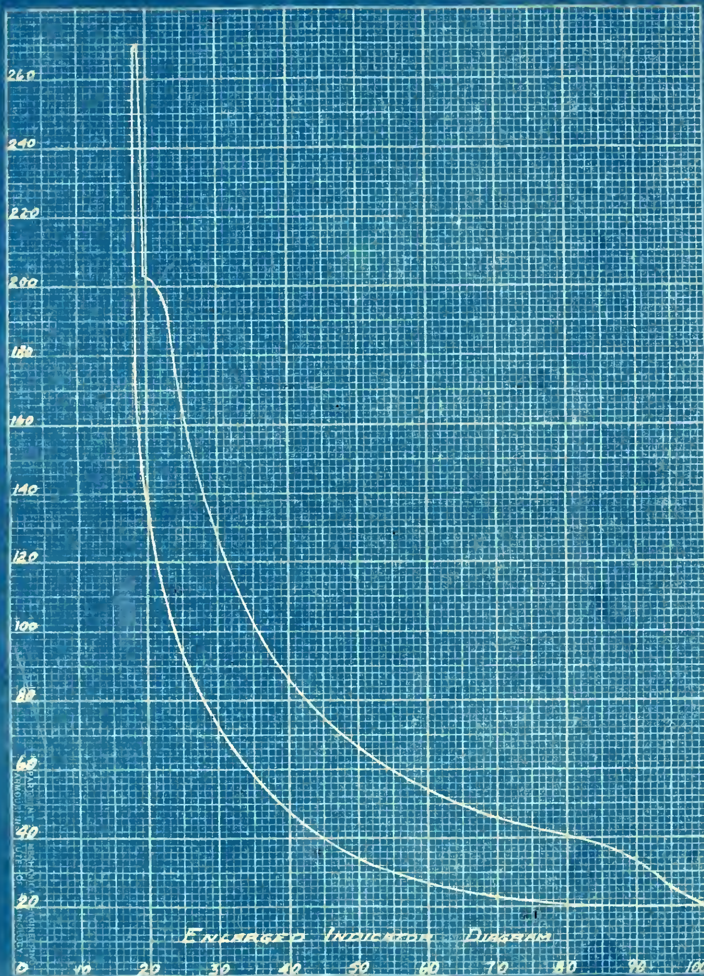


CONSTANT PRESSURE LINES
VOLUME TEMPERATURE DIAGRAMS
4225 BTU
PRESSURE IN LBS PER SQ IN ABSOLUTE
ABSOLUTE TEMPERATURE DEGREES FAHR.
VOLUMES IN PER CENT OF VOLUMES OF CHARGE AT ATMOSPHERE PRESSURE






FOR COMPRESSION N = 1.45
FOR EXPANSION N = 1.25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ENLARGED INDICATOR DIAGRAM

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Discussion of Diagrams.

The diagrams on the preceeding page were laid out in accordance with the directions given in laboratory manual on a test of a 3 cylinder Westinghouse gas engine, which is quoted on the following page. The only variation from these directions occurred in the determination of the volume of charge at atmospheric pressure. This was found by extending the line of compression, on the logarithmic diagram, until it intersected the atmospheric line. This intersection occurred at 83% of the total volume. This point was taken as 100% on the P V diagram and the curve plotted in accordance to the directions contained in the following pages.

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Taken from Laboratory Notes on a Westinghouse Gas Engine:

We are furnished with a chart as represented by the accompanying blue print, on which - the lower horizontal scale is that of volumes in per cent of volume charge at atmospheric pressure; the left vertical scale is that of absolute pressure as given on the indicator card; the right vertical scale is that of absolute temperature of gases in degrees of Fahrenheit; the top horizontal scale extending down the right vertical is that of the extension of the lines of constant pressure of temperature volume diagram. They are drawn from the center O, lower right hand corner of diagram.

Curved lines marked Log. $\frac{V}{V_1}$ Log. $\frac{T}{T_1}$ 2.45 Log. $\frac{T}{T_0}$ are also shown and will be explained at length later on.

The volume of charge at atmospheric pressure is represented as 100% and the relation

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of pressure volume and temperature is taken for 140 F. = 600°abs. for the charge at 100% and atmospheric pressure. This is given as

$$\frac{P'' \times V\%}{T} = 2.45$$

where volume is in per cent, pressure V for square inches and absolute temperature. To lay out the P V diagram on chart we have a card from the engine accompanying report. We use only one from right hand cylinder though it is understood that in practice a combination should be made from cards for all three cylinders, giving a typical average performance for the engine, light spring card should have been taken from theengine to locate the atmospheric dimension of charge or where the compression line crosses the atmospheric pressure line.
In the absence of this we calculate it from the pressure of compression. In this card it is 100 pounds absolute and this for adiabatic compression corresponds to a clearance volume

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= 25 3/4%.

As we know that compression is accompanied by cooling we can take a lower value, say 23%. The clearance in engine is 110" for the right hand cylinder.

Hence the volume of charge = $\frac{110}{23}$ = 477, of which the piston travel to full charge = 477 - 110 = 367". Per cent of piston travel to full charge = 376 ÷ 503 = 73% when 503 = volume of travel.

We have taken 75% as the volume for convenience and lay off 75% of the card length, draw a vertical 100% line, then making the line of greatest compression equal 23% gives us a scale of volume as laid out when greater volume equals 125% of the volume of charge and clearance at atmospheric pressure. Drawing the line of absolute zero 15# below the atmospheric line, the pressures are marked as shown, and with these volumes in per cent and pressure absolute, the card is drawn on the chart and edged with

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green to distinguish it.

To draw the temperature volume diagram (T, V,) take any point on the P V diagram, such as Y , the coordinates of which are 150# and 40% V, stretch a thread from a center at O to 150 pound line on scale at top of diagram and mark where it crosses the vertical projection of 40% or Y. The point Y' is a point on the T V diagram and shows that the temperature at this point is 2400° F. absolute. The other points on the diagram are found in a similar manner, except at the bottom where the points fall below the 600° line, which is unreasonable, there being no effectual cooling at this time, hence the line was on slowly rising temperature and the diagram has been edged with yellow to distinguish temperature volume diagram.

It will be noted that the highest temperature, 3100° absolute is not at the highest pressure, but shortly afterwards that the rapid

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fall of temperature due to cooling and expansion is soon checked by after burning so that temperature remains constant and even rises slightly at end of expansion.

To draw the temperature entropy diagram, the formula for entropy may be given as E $= \frac{K}{C}$ log. $\frac{T}{T_0}$ log. $\frac{V}{V_0}$ where $\frac{K}{C} = \frac{C_v}{C_p - C_o}$; this for various gases has been figured as follows:

Gas illuminating and natural	= 3.14
Air	= 2.44
Exhaust gases	= 2.44
Mixture	= 2.45

It is proper then to use for both mixture and burning and exhaust gases a value of 2.45. The curve marked log. $\frac{T}{T_0}$ gives graphically the values measured from any vertical line, say 150%. This multiplied by 2.45 gives a second curve marked log. $\frac{T}{T_0}$ x 2.45 which shows the values of the first member of the formula for entropy. The curve marked log. $\frac{V}{V_0}$ shows the variation of values measured from a hori-

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zontal line, say that of 0, but any horizontal line may be used, the effect being to merely shift the whole diagram to the right or left. Hence, if we choose line 100#, for our datum to line point Y' on T V diagram, measure up from datum to line log. $\frac{V}{V_0}$ and add this to the line 2.45 log. $\frac{T}{T_0}$ at the point where a horizontal line from Y' intersects N, we get the point Y''. On the entropy curve find other points in a similar manner, remembering, that where we have to measure down from datum to curve, it is minus and is to be laid off to the right from 2.45 log. $\frac{T}{T_0}$.

The entropy curve is edged with red to distinguish it. With a planimeter we measure the areas to find heat units of various conditions, thus;

The area of the line made in red = Heat expended in work.

The area under C D to O line = Heat absorbed by compression.

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The area under C A = Heat added during explosion.

The area under A Y" = Heat absorbed by cooling during part of expansion.

The area under Y"B = Heat added by after-burning, over absolute expansion.

The area under B D = Heat lost in exhaust gases.

There is also heat lost to cooling water which was measured in the efficiency test and amounted to 33.5% of the total energy. The heat lost by radiation and unburned gases can only be obtained by differences.

From the test we have the heat shown in I.H.P. the same as the area bounded by red = 19%. Hence the total heat of one pound mixture may be obtained by dividing the area = 12.33 by 19 = 64.8" from which the heat balance and distribution of heat transfer may be obtained.

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Attention is called to cooling during expansion more than burning that decreases the entropy from A to Y" and the over-balancing of this by the after burning causing an increase of entropy from Y" to B, when expansion passes from constant temperature expansion to that of a rising temperature.

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Discussion.

A great deal of trouble was encountered in starting the engine. The crank would oscillate through an angle of about 300° but at no time would it pass the upper dead center against compression. The compression pressure was decreased by connecting a long tube, with a check valve on the end of it, to the indicator cock, but still the engine would not pass compression. Lighter fuels, such as gasoline and even ether were tried, but without results. In dis-assembling the engine, care was taken to leave the governor set at the same angle as before, in order that trouble from this source would be avoided. As a last resort the governor was moved to give a later injection of the fuel and this proved to have been the source of trouble, as the explosion occurred before the piston reached the upper end of its stroke, thus forcing it back down.

Another source of trouble was the hot bulb.

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This would often become heated to a too high temperature, thus causing preignition of the fuel, which gave the same oscillation of the flywheel as when injection was early.

The cooling water also controls this to a certain extent. If a large amount of water is circulated around the cylinder the temperature in the engine will be decreased and a higher compression required for ignition. The engine must be comparatively cool in order to start it without being troubled with the flywheel oscillating.

After the governor cam was adjusted to give the proper injection, the governor spring was tightened to the maximum to give the greatest speed. The engine was then started and the load applied. The water brake was very sensitive to the slightest adjustment of the amount of water applied and the engine would slow down or speed up correspondingly, almost simultaneous with the adjustment of the load.

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The engine was allowed to run for about an hour before test readings were taken. Indicator cards were taken during this period and the load and cooling water varied to give the greatest power possible. A run of fifteen minutes was made and reading taken of the weight of fuel and cooling water, temperature of inlet and outlet cooling water, speed and indicator cards. The load was kept constant. The speed increased during the test, indicating that the cooling water was becoming warmer, giving the engine more power.

The fuel consumed appears to be rather high but this may be due to leakage in the rubber hose connecting the supply tank and the pump, although no leakage was discernable.

The continuance of tests was obstructed by a joint connecting the tube from the pump to the nozzle. This joint was disconnected so another nozzle could be tested. As there was nothing which could be applied to replace

this joint the test had to be discontinued, and time would not permit another test to be made after the broken joint could be replaced from the factory.